Impact of Capping Stack on Well Flow Rate

During a series of experiments a flow estimate of 53,000 bopd was obtained from the Macondo well. This flow rate occurred with a measured capping stack pressure of 2600 psi. However, since this capping stack pressure is above the nominal ambient pressure of 2200 psi, it is reasonable to assume that the flow out of the Macondo well was reduced by the presence of the capping stack. To estimate this effect, a simple model is presented here.

It is assumed that the average reservoir pressure during the flow experiments was 10,050 psi. The sea pressure at the well exit is 2200 psi, and the capping stack pressure was measured as 2600 psi. Various terms account for the pressure difference between the reservoir and the capping stack. The elevation head in the well is grossly estimated as 3000 psi at the conditions during the experiment. The elevation head varies depending upon the choice of the flow path. If the flow path is up the annulus (outside of the 9 and 7/8 inch casing), there is a high frictional pressure drop and a low average pressure in the well. The low average pressure yields low fluid densities and a low elevation head. If the flow path is up the center, frictional pressure drop is lower yielding a higher elevation head. The remaining pressure difference is assumed to be due to flowing friction. The equation below calculates the frictional pressure drop with the capping stack:

$$\Delta P_{friction-WCS} = 10050 - 3000 - 2600 = 4450\ psi$$

Part of this friction is due to Darcy flow within the reservoir (well drawdown), and part of it is due to resistance entering the well (well skin). It is assumed that the sum of the well drawdown and the well skin was 1000 psi. This is consistent with a productivity index of 50 bopd/psi and a nominal flow of 50,000 bopd.

It is assumed that the elevation head does not change significantly with changes in the flow rate. This allows calculation of an original frictional pressure difference (without the capping stack) by replacing the measured capping stack pressure (2600) with the ambient pressure (2200):

$$\Delta P_{friction-NCS} = 10050 - 3000 - 2200 = 4850\ psi$$

It is typically assumed that both the well drawdown and the well skin varies linearly with flow rate (laminar flow). The remaining portion of the pressure drop is typically assumed to vary with the square of the flow rate (turbulent flow). With this scaling, we can calculate the flow rate increase that existed without the capping stack:

$$\Delta P_{friction-NCS} = \Delta P_{laminar-WCS}\left(\frac{Q}{Q_{WCS}}\right) + \Delta P_{turbulent-WCS}\left(\frac{Q}{Q_{WCS}}\right)^2$$

All of the terms with the capping stack are known (the laminar flow pressure drop is 1000 psi, the turbulent flow pressure drop is 3450 psi, and the flow rate is 53,000 bopd). So if the altered total friction pressure drop is 4850 psi, one determines an altered flow rate of 55,600 bopd. Thus, the flow rate decreased by 5% due to adding the capping stack.

One can use this same method to estimate the flow rate of the well when the reservoir was not depleted. The frictional pressure drop is substantially increased if the reservoir pressure is assumed to be 11,850 prior to depletion:

$$\Delta P_{friction-max} = 11850 - 3000 - 2200 = 6650\, psi$$

Note that this describes a fictional initial state since the model implicitly assumed that the well geometry does not change during the 85 days of flowing this well. In fact many geometry changes occurred. These include, but are not limited to, the riser and kink being cut off, junk shots, and erosion. The maximum flow rate is estimated as 66,300 bopd.

The estimates provided in this document are very approximate. They depend upon an estimate of the elevation head, which varies by +/- 500 psi depending upon the choice of the flow path (annular or central). The estimate also depends upon the assumption that the elevation head does not vary in the various flowing conditions analyzed.

Finally, the maximum flow is a fictitious state, but it may provide a reasonable estimate of the initial flowing conditions once the effect of the riser and kink restrictions are added.

To enable integration of the flow from the first day to the last, one is required to accept a model for the reservoir. Various models of the reservoir could result in a different transient between the initial state and the final state.